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COMPARING COMPUTER RUN TIME OF BUILDING SIMULATION PROGRAMS

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ABSTRACT

This paper presents an approach to comparing computer run time of building simulation programs. The computing run time of a simulation program depends on several key factors, including the calculation algorithm and modeling capabilities of the program, the run period, the simulation time step, the complexity of the energy models, the run control settings, and the software and hardware configurations of the computer that is used to make the simulation runs. To demonstrate the approach, simulation runs are performed for several representative DOE-2.1E and EnergyPlus energy models. The computer run time of these energy models are then compared and analyzed.

KEYWORDS

Computer Run Time, Simulation Program, DOE-2, EnergyPlus

INTRODUCTION

With the trend toward energy efficient building designs, energy simulation programs are widely employed in the design process to help architects and engineers to determine what design alternatives save energy and are cost effective. DOE-2 is one of the popular programs used by the building simulation community. With today's PC computing power, a DOE-2 energy model normally takes less than a few minutes to complete an annual simulation run. DOE-2's computing efficiency builds upon its hour-by-hour calculations and the sequential software structure of LOADS-SYSTEMS-PLANT-ECONOMICS which does not integrate the building envelope thermal dynamics with the HVAC system operating performance simultaneously. EnergyPlus is a new generation simulation program built upon the beauties of both DOE-2 and BLAST, and adds new modeling features beyond the two programs. With DOE-2's limitations in modeling emerging technologies, more and more modelers have begun using EnergyPlus for their simulation needs, especially for LEED green building designs and low or net-zero energy buildings. EnergyPlus does sub-hourly calculations and integrates the load and system dynamic performance into the whole building energy balance calculations which can provide more accurate simulation results.

The fact is that compared with DOE-2, EnergyPlus runs much slower. But why and how does EnergyPlus run slower? What is the basis of the comparison? Is the comparison apple-to-apple? It is worth digging into these questions to find out what are under the hood for a full and clear understanding of computer run time of simulation programs.

This paper introduces an approach to compare computer run time of building simulation programs.

APPROACH

Metric for Comparing Simulation Run Time

For automobile industry, the MPG (miles per gallon) is the metric or criterion to benchmark the fuel efficiency of vehicles. Unfortunately there is no such de facto metric to compare computer run time of simulation programs. Key factors that have significant impacts on simulation run time include: the calculation algorithm and modeling capabilities of the program, the run period, the simulation time step, the complexity of the energy models, the run control settings, and the software and hardware configurations of the computer that is used to make the simulation runs. With the complexity involved, it is almost impossible to define a theoretical metric to represent the computing efficiency of a simulation program. Fortunately, in practice, we can use simple metric like SPZ (Seconds per Zone) to compare computer run time among simulation programs.

The SPZ is defined as the total amount of computer run time divide by the total number of thermal zones of an energy model run with a simulation program. The SPZ has a unit of seconds per zone. The less the SPZ, the more efficient computing a simulation program has.

Complexity of Energy Models

It is hard to quantitatively define the complexity of an energy model. What is certain is types of energy features and the size of building and HVAC systems, to a great extent, determines the complexity of an energy model. The energy features may include: shading of envelope and windows, daylighting and controls, HVAC system types and configurations, plant equipment types and controls, service water heating systems, and renewable energy productions. The size of building and HVAC systems relates to the number of opaque surfaces, the number of openings (windows, doors, skylights), the number of thermal zones, the number and tyeps of HVAC systems, and the number of primary loops and plant equipment.

Even with DOE-2, if there are lots of shading devices and daylighting calculation is turn on, an annual 8760-hour simulation can take much longer to run.

User Control of Simulation Runs

For a specific simulation program, user inputs to some of the run control settings play a significant role in the amount of computer run time needed to complete a simulation run. The settings of run controls include the number of simulation time steps per hour, choice of solution algorithm, and convergence resolution.

For DOE-2, users have very limited inputs to control the simulation run time as the computing time step is fixed at an hour and it is almost impossible to change the calculation algorithms. What users can change are the run period, whether to consider the self shading effects of building facades, accuracy of the shading calculations, and which output reports to produce.

For EnergyPlus, users have much more control on run time. Users can change the field inputs of several IDD objects to control the run time:

- Simulation run period. Whether whole year, several months, one month, several weeks, one week, several days, or even one day.
- Time step for loads calculations. From a small time step of one minute to a large time step of sixty minutes (hourly) per hour.
- Heat balance solution algorithm. Choices among CTF, EMPD, and CondFD.
- Solar distribution calculation algorithm. Choices among MinimalShadowing, FullExterior, FullInteriorAndExterior, FullExteriorWithReflections, and FullInteriorAndExteriorWithReflections.
- System convergence limits. Choices of minimum system time step (from 1 minute to 60 minutes) and maximum HVAC iterations (from 5 to 200 or more).
- Shadow calculation interval. Choices of from one day to three weeks, or to whatever is appropriate for the application.
- Whether to do the auto-sizing runs for zones, systems, and plants.
- Report generating. Whether to produce summary reports, monthly reports, and hourly or sub-hourly reports.

Basis of Comparing Computer Run time

As different simulation programs may have different software architecture, use different algorithms to model building and energy systems, and require different user inputs even to describe the same building envelope or HVAC system component, it is not feasible to develop an identical energy model with two simulation programs. To get as close as possible for an apple-to-apple comparison of computer run time of simulation programs, simulation programs must be run on a common basis with –

- The same building and energy systems and their control strategies.
- The same simulation run period
- The same physical and temporal resolutions
- The same or as close as possible user settings: time step, calculation algorithm, and solver convergence tolerance
- The same computer with same hardware and software configurations

SIMULATION RUNS

To demonstrate the above described approach, several building prototypes with different occupancy types, different number of zones and system types, are used to generate the EnergyPlus and DOE-2 models. These models were originally developed by Joe Huang at Lawrence Berkeley National Lab and further modified and enhanced by NREL and PNNL for the DOE new commercial building benchmarks. Both DOE-2.1E version 124 and EnergyPlus version 2.1.0 are used to run these models, and computer run times are listed in tables for comparisons.

Commercial Building Prototypes

Three building prototypes are used for comparing the simulation run time. Details of these prototypes are documented in score cards (Huang 2007).

The large office building

The large office building has a rectangle shape with twelve floors. The top, bottom and a typical middle floor are modeled explicitly. The middle floor has a floor multiplier of ten to represent other nine middle floors. Each floor has four perimeter and one core zones. The total number of zones is 15. The building is served by one central variable air volume (VAV) systems with chillers and boilers. Perimeter zones have reheat boxes. The window-wall-ratio is 40% with windows uniformly distributed on four facades.

The secondary school

The secondary school is a campus with 11 buildings. The energy model has a total of 79 thermal zones. The building is served by 11 packaged single zone systems with direct expansion cooling and gas furnace heating. The window-wall-ratio is 33%.

The hospital building

The hospital building has a rectangle shape with five floors. Each floor has different zoning pattern. The total number of zones is 55. The building is served by 7 central VAV systems and 1 constant volume air system. The window-wall-ratio is 20%.

Climate Zones

The San Francisco weather file is used for all simulation runs.

Simulation Results

Annual runs of these prototype models are performed with both DOE-2 and EnergyPlus on a desktop PC with Intel Core 2 Duo 3GHZ 2 CPUs and 2GB of RAM. The DOE-2 runs do not consider any shades. The EnergyPlus runs have default settings of minimal solar shading, 15-minute loads time step, system minimum time step of 6 minutes, 20 system maximum interactions, and conduction transfer function heat balance calculations. HVAC is autosized in all DOE-2 and EnergyPlus runs. All standard summary reports are requested from both DOE-2 and EnergyPlus runs. No daylighting is considered in these runs.

Tables 1 to 3 show EnergyPlus runs at 15-minute time step compared with DOE-2's 60-minute time step.

Table 1 Computer Run Time of the Large Office Building

SIMULATION PROGRAM	TOTAL RUN TIME (SECONDS)	SPZ (SECONDS/ZONE)
DOE-2.1E v124	0.74	0.049
EnergyPlus v2.1.0	77	5.13

Table 2 Computer Run Time of the Secondary School

SIMULATION PROGRAM	TOTAL RUN TIME (SECONDS)	SPZ (SECONDS/ZONE)
DOE-2.1E v124	5.1	0.065
EnergyPlus v2.1.0	657	8.32

Table 3 Computer Run Time of the Hospital Building

SIMULATION PROGRAM	TOTAL RUN TIME (SECONDS)	SPZ (SECONDS/ZONE)
DOE-2.1E v124	2.6	0.047
EnergyPlus v2.1.0	499	9.24

To have a fair comparison, another set of EnergyPlus runs are made at 60-minute loads and system time step and 5 maximum HVAC iterations. Tables 4 to 6 show the results.

Table 4 Computer Run Time of the Large Office Building

SIMULATION PROGRAM	TOTAL RUN TIME (SECONDS)	SPZ (SECONDS/ZONE)
DOE-2.1E v124	0.74	0.049
EnergyPlus v2.1.0	18.4	1.23

Table 5 Computer Run Time of the Secondary School

SIMULATION PROGRAM	TOTAL RUN TIME (SECONDS)	SPZ (SECONDS/ZONE)
DOE-2.1E v124	5.1	0.065
EnergyPlus v2.1.0	158	2.0

Table 6 Computer Run Time of the Hospital Building

SIMULATION PROGRAM	TOTAL RUN TIME (SECONDS)	SPZ (SECONDS/ZONE)
DOE-2.1E v124	2.6	0.047
EnergyPlus v2.1.0	138	2.55

Results Analysis

At 15-minute time step, EnergyPlus runs much slower than DOE-2.1E by a factor of from 105 for the large office building to 196 for the hospital building. At 60-minute time step, EnergyPlus still runs slower than DOE-2.1E by a factor of from 25 for the large office building to 54 for the hospital building, but EnergyPlus computer run time improves by a factor of about 4 which corresponds to the reduction of number of time steps per hour from 4 to 1.

The main reason EnergyPlus runs much slower than DOE-2.1E is that EnergyPlus does the integrated heat balance calculations for loads, systems, and plant at a given time step while DOE-2 does sequential calculations from loads to systems to plant with no feedbacks from plant to systems or from systems to loads. This means EnergyPlus may need some iterations within a time step in order to reach a convergent solution. Details of comparing modeling features between DOE-2 and EnergyPlus can be found at (Crawley et al. 2005).

When DOE-2 was first developed in late 1970s, the computer computing power was very limited. Even a simple 50-zone model could take hours if not days to run. With today's PC computing power, the question is not to develop simulation programs that run as fast as DOE-2, but rather to develop programs that can do sub-hourly and more accurate building thermal performance calculations in a reasonable amount of time. If EnergyPlus can reach 10 seconds per zone, a typical 50-zone 5-system model would need about 10 minutes to complete an annual run with currently available PCs (3 GHZ CPU and 2 GB of RAM). Note that for the rather simple modeling runs performed for this paper, EnergyPlus in all cases performed faster than 10 seconds per zone. For cases where only monthly and annual energy consumption results are needed, hourly time step may be sufficient. In that case EnergyPlus is in the range of 2 seconds per zone. If in future EnergyPlus can take advantages of multiple CPUs in a single PC, the simulation run time could be cut significantly.

CONCLUSION

This paper introduces an approach to comparing computer run time of building simulation programs. Energy models developed from same building prototypes with similar user run control settings should be the basis of runs with different simulation programs for the purpose of comparing computer run time.

Modelers should not expect different programs to run at the same speed if these programs have very different modeling capabilities and run at different time steps with different calculaton algorithms for different simulation accuracy.

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